A THIN MAGNETIC FILM SHIFT REGISTER

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A Thin Magnetic Film Shift Register*

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Summary—**An initial application of the dynamics and interactions of domains within continuous magnetic thin film structures is made to a shift register in which binary information is stored and translated in and along a continuous evaporated thin magnetic film. These thin magnetic film shift registers are capable of storing information having a density of several hundred bits per square inch of vacuum evaporated structure and of translating this amount of information at bit rates in excess of a megacycle with powers of less than 10 watts.**

Introduction

THE dynamics and interactions of domains[1] within continuous magnetic thin film structures may be applied to a variety of information processing or computing functions. A useful initial application of this concept is to a shift register in which binary information is stored and translated in and along a continuous evaporated thin magnetic film. This operation may be pictured as analogous to a magnetic drum surface on which the "bits" move instead of the drum. The basic simplicity of continuous shifting systems which eliminate the usual cell to cell coupling networks makes such an approach extremely attractive. Magnetic shifting involving continuous wire structures has been reported.[2] In the film system to be described, the very-high-volume density of stored information, the low power of operation, the relatively high speed of operation, and the automated production potential indicate unusual system possibilities.

Theoretical Considerations

The operation of this device can be explained, in a preliminary way, on the basis of a difference which can be made to exist between the energy required to establish or create a particular domain configuration within the magnetic continuum, and the energy required to translate the given domain configuration a distance through the continuum. This difference allows "written" domains to be moved unilaterally under the influence of periodically pumped forcing fields without these fields introducing any spurious information.

The specified energy difference may be inferred from the following considerations. The creation energy for establishing a given domain configuration within a magnetic continuum contains conservative terms such as the magnetostatic, magetocrystalline, and exchange energies, as well as the dissipative terms associated with switching the magnetic material. The translation energy for moving a given domain contains only a dissipative energy term, with the conservative terms remaining constant (provided that the domain is translated within a uniform magnetic continuum under conditions which preserve its domain configuration and relation to its environment). Considering the control that can be exercised over these various components, a design may be selected in which it is possible to drive propagating electrodes hard enough to move domains, but not hard enough to create domains. The domain is created by a separate writing electrode and current.

A more complete consideration of the operational theory of this device must also take account of certain "rate factors," such as domain nucleation times and wall motion damping effects. These factors become increasingly important in the design of maximum speed registers.

Propagation of a domain through the magnetic film consists of translating the walls of the domain in phase to preserve the essential domain configuration. One combination of magnetic film and electrode structure for achieving this shifting action is represented in Fig. 1. Fig. 2 is an exploded view of this vacuum deposited configuration. This configuration provides means 1) for supplying the creation energy to the magnetic film through application of current to the writing electrode, 2) for supplying propagating energy to the magnetic film through application of current to the propagating electrodes, and 3) for detecting the flow of domains through the induced voltage in the readout electrode looping the magnetic film.

The configuration's operation in moving "written" domains under the influence of periodic, continuously pumped forcing fields is shown in a series of longitudinal cross sections of Fig. 3. Row 1 of Fig. 3 shows the shifting configuration with its magnetic film magnetized to the right throughout. Current is passed through the writing electrode with a direction and magnitude to reverse the magnetization of the magnetic material lying under its influence. This brings about the condition of the magnetic film shown in Row 2. Row 3 represents the translated state of the domain after current of the proper magnitude and sense has been passed through the upper propagating electrode set. The arrows indicate the alternating H field pattern set up by the flow of the current. These fields are seen to be of the proper polarity in the vicinity of the domain walls to induce

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[1] D. W. Moore, "Magnetic domain switching in evaporated magnetic films," *Proc. 1959 Electronic Components Conf.*, p. 11; May, 1959.

[2] A. H. Bobeck and R. F. Fischer, "Reversible diodeless twister shift register," *J. Appl. Phys.*, vol. 30, pp. 43–44; April, 1959.

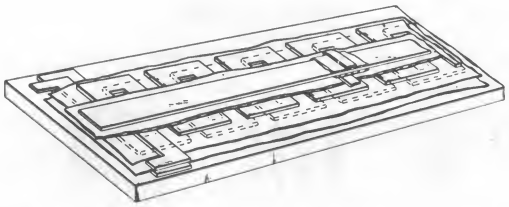

Fig. 1—Artist's sketch of the vacuum evaporated thin film shift register.

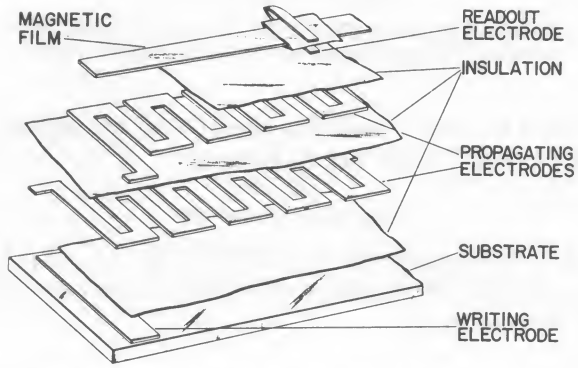

Fig. 2—Exploded view of the thin film shift register.

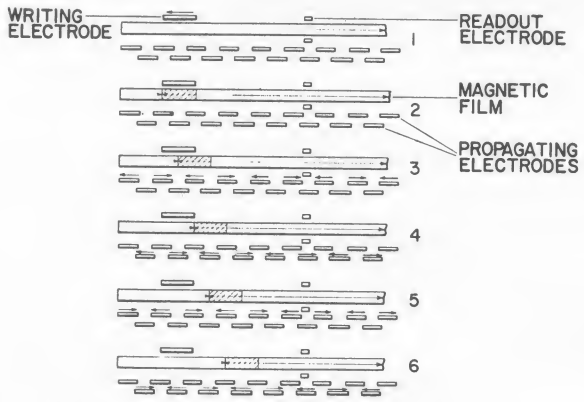

Fig. 3—A series of longitudinal cross sections demonstrating the propagating-current pattern and the shifting sequence of the register. The cross-hatched area represents a domain of reverse magnetization within the continuous magnetic film.

wall motion in the appropriate direction to translate and preserve the domain. This translation brings the domain into proper position with respect to the lower propagating electrode set. Row 4 represents the further translated state after the application of current to the lower electrode set. For the next translation, a reversed current is required through the upper propagating electrode bringing about the configuration of Row 5, and the next translation to Row 6 requires a reversed current in the lower propagating electrode. The domain is now in a position for the pattern to be repeated.

This basic four-beat propagating pattern provides the unilateral flow of domains and may be pumped continuously. Because of its subcritical field nature, the pattern is effective only in moving established domains and not in creating or establishing new domains. Obviously, the direction of information flow may be reversed by reversing the propagating pattern. Because of the spacing and width of the information domains within a single magnetic strip, four propagation pulses are required to transport the complete bit configuration past a particular fixed reading station. A register in which information may be read at every propagating pulse time is realized by using four magnetic strips in parallel with offset READ and WRITE electrodes.

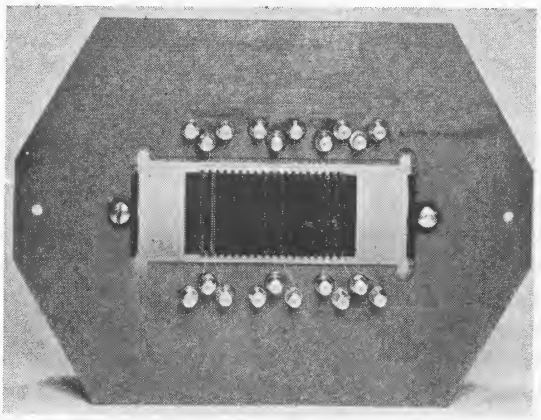

Fig. 4—A photograph of an experimental vacuum evaporated shift register. The register measures 1.5 inch×0.9 inch.

Experimental Registers

Fig. 4 shows an experimental thin film shift register which has been operated at propagating pulse frequencies in excess of one megacycle. This register was produced using sequential vacuum evaporation techniques[3] in depositing magnetic,[4] conducting, and insulating materials in patterns corresponding to Fig. 2. The magnetic material is deposited in an orienting magnetic field giving a preferred direction of magnetization along the length of the strip. The sequence of deposition shown in Fig. 2 was inverted, with the magnetic strips lying nearest to the substrate. The information is translated 0.020 inch during every propagating pulse, permitting 50 bits to be stored in one linear inch of the shift register. Several of these registers may easily be placed side by side in the space of one lateral inch and may be driven by a common set of propagating electrodes. In practice, this provides a surface storage density of several hundred bits per square inch.

The power required to drive a register is set primarily by the resistance of the propagating electrodes. The register of Fig. 4 requires a power of 8 watts for operation at a megacycle and 2 watts for 100-kc operation. The propagating electrode currents are 0.45 and 0.90 ampere respectively, giving H fields at the surface of the magnetic strip of 3.7 and 7.4 oersteds.

[3] K. D. Broadbent, "A vacuum evaporated random access memory," *Proc. Special Tech. Conf. on Nonlinear Magnetism and Magnetic Amplifiers*, Am. Inst. Elec. Engrs., New York, N. Y., pp. 281–286; September, 1959.

[4] M. S. Boise, Jr., "Preparation of thin magnetic films and their properties," *J. Appl. Phys.*, vol. 26, pp. 975–980; August, 1955.

Using a magnetic strip having a width of 0.040 inch, four registers (comprised of four strips each) can be placed under the propagating structure visible in Fig. 4. The pictured unit has a capacity of 300 bits. The propagating electrodes are 0.030 inch wide and spaced 0.010 inch apart, the writing electrode is 0.040 inch wide, and the readout electrodes are 0.005 inch wide. The conducting and insulating layers range from one to three microns in thickness. The magnetic strips are 900 A thick, composed of 75 per cent nickel and 25 per cent iron, and the electrical output signals at a megacycle rate are about 1 mv in amplitude. Greater densities or larger outputs may be achieved with other designs.

The configuration of the information bit in the magnetic strip may be varied widely, depending upon the combination of geometric and material factors employed. Exceptionally high bit density registers may be operated in which the information bit is a single quasi-elliptical domain. Other registers show the bit to be a cluster of elliptical domains and still others may be operated with a semirectangular domain having a fine-structured domain boundary. Examples of these configurations are shown in Fig. 5. Photographs of the domains were obtained using the Kerr magneto-optic effect.[5] This device and its operational principles are covered by a United States Patent.[6]

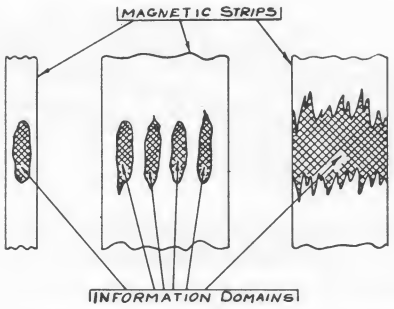

Fig. 5—Facsimiles of magneto-optic Kerr photographs showing domains within various evaporated shift register strips.

Acknowledgment

The contributions of F. J. McClung, Jr., and A. I. Braunstein to the development of this project are gratefully acknowledged.

[5] C. A. Fowler and E. M. Fryer, "Magnetic domains by the longitudinal Kerr effect," *Phys. Rev.*, vol. 94, pp. 52–56; April 1, 1954.
[6] K. D. Broadbent, U. S. Patent No. 2,919,432; assigned to Hughes Aircraft Co., December 29, 1959.